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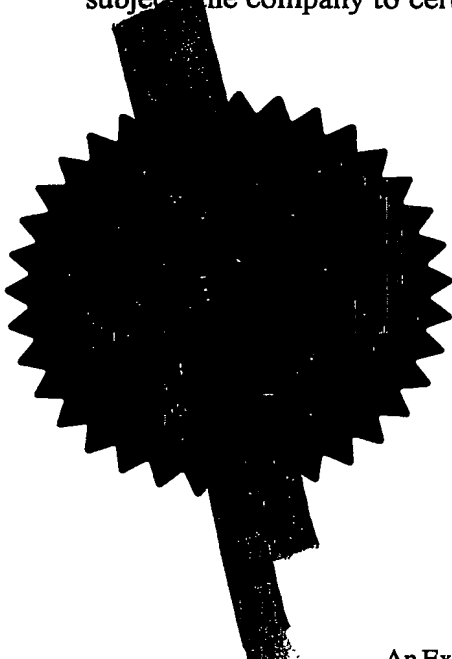
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P01/7700 0.00-0302604.4

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### 1. Your reference

CASE NO. 26

### 2. Patent application number (The Patent Office will fill in this part)

0302604.4

- 5 FEB 2003

### 3. Full name, address and postcode of the or of each applicant (underline all surnames)

AVIDEX LTD  
57C MILTON PARK,  
MILTON,  
ABINGDON  
OXFORDSHIRE  
OX14 4RX

Patents ADP number (if you know it)

If the applicant is a corporate body, give the country/state of its incorporation

ENGLAND 7734429002

### 4. Title of the invention

RECEPTORS

### 5. Name of your agent (if you have one)

"Address for service" in the United Kingdom to which all correspondence should be sent (including the postcode)

MR. ALAN WALLS  
AVIDEX LTD  
57C MILTON PARK  
MILTON  
ABINGDON  
OXFORDSHIRE  
ENGLAND  
OX14 4RX

Patents ADP number (if you know it)

8480618001

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## RECEPTORS

The present invention relates to single-chain T cell receptors (TCRs).

### 5     Background to the Invention

#### *Native TCRs*

As is described in, for example, WO 99/60120 TCRs mediate the recognition of specific Major Histocompatibility Complex (MHC)-peptide complexes by T cells and, as such, are essential to the functioning of the cellular arm of the immune system.

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Antibodies and TCRs are the only two types of molecules which recognise antigens in a specific manner, and thus the TCR is the only receptor for particular peptide antigens presented in MHC, the alien peptide often being the only sign of an abnormality within a cell. T cell recognition occurs when a T-cell and an antigen presenting cell (APC) are in direct physical contact, and is initiated by ligation of antigen-specific

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TCRs with pMHC complexes.

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The native TCR is a heterodimeric cell surface protein of the immunoglobulin superfamily which is associated with invariant proteins of the CD3 complex involved in mediating signal transduction. TCRs exist in  $\alpha\beta$  and  $\gamma\delta$  forms, which are structurally similar but have quite distinct anatomical locations and probably functions. The MHC class I and class II ligands are also immunoglobulin superfamily proteins but are specialised for antigen presentation, with a highly polymorphic peptide binding site which enables them to present a diverse array of short peptide

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fragments at the APC cell surface.

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The extracellular portion of native heterodimeric  $\alpha\beta$ TCR consists of two polypeptides each of which has a membrane-proximal constant domain, and a membrane-distal variable domain (see Figure 1). Each of the constant and variable domains includes an intra-chain disulfide bond. The variable domains contain the highly polymorphic loops analogous to the complementarity determining regions (CDRs) of antibodies.

CDR3 of the TCR interacts with the peptide presented by MHC, and CDRs 1 and 2 interact with the peptide and the MHC. The diversity of TCR sequences is generated via somatic rearrangement of linked variable (V), diversity (D), joining (J), and constant genes. Functional  $\alpha$  chain polypeptides are formed by rearranged V-J-C regions, whereas  $\beta$  chains consist of V-D-J-C regions. The extracellular constant domain has a membrane proximal region and an immunoglobulin region. There is a single  $\alpha$  chain constant domain, known as TRAC, and two different  $\beta$  constant domains, known as TRBC1 and TRBC2 (IMGT nomenclature). There are four amino acid changes between these  $\beta$  constant domains, three of which are within the domains used to produce the single-chain TCRs of the present invention. These changes are all within exon 1 of TRBC1 and TRBC2:  $N_4K_5 \rightarrow K_4N_5$  and  $F_{37} \rightarrow Y$  (IMGT numbering, differences TRBC1  $\rightarrow$  TRBC2), the final amino acid change between the two TCR  $\beta$  chain constant regions being in exon 3 of TRBC1 and TRBC2:  $V_1 \rightarrow E$ . The extent of each of the TCR extracellular domains is somewhat variable. However, a person skilled in the art can readily determine the position of the domain boundaries using a reference such as The T Cell Receptor Facts Book, Lefranc & Lefranc, Publ. Academic Press 2001.

#### *Single Chain TCRs*

Single-chain TCRs (scTCRs) are artificial constructs consisting of a single amino acid strand, which like native heterodimeric TCRs bind to MHC-peptide complexes. Unfortunately, attempts to produce functional alpha/beta analogue scTCRs by simply linking the alpha and beta chains such that both are expressed in a single open reading frame have been unsuccessful, presumably because of the natural instability of the alpha-beta soluble domain pairing.

Accordingly, special techniques using various truncations of either or both of the alpha and beta chains have been necessary for the production of scTCRs. These formats appear to be applicable only to a very limited range of scTCR sequences. Soo Hoo *et al* (1992) PNAS. 89 (10): 4759-63 report the expression of a mouse TCR in single chain format from the 2C T cell clone using a truncated beta and alpha chain linked

with a 25 amino acid linker and bacterial periplasmic expression (see also Schodin *et al* (1996) Mol. Immunol. **33** (9): 819-29). This design also forms the basis of the m6 single-chain TCR reported by Holler *et al* (2000) PNAS. **97** (10): 5387-92 which is derived from the 2C scTCR and binds to the same H2-Ld-restricted alloepitope. Shusta *et al* (2000) Nature Biotechnology **18**: 754-759 report using single-chain 2 C TCR constructs in yeast display experiments, which produced mutated TCRs with, enhanced thermal stability and solubility. , this report also demonstrated the ability of these displayed 2C TCRs to selectively bind cells expressing their cognate pMHC. Khandekar *et al* (1997) J. Biol. Chem. **272** (51): 32190-7 report a similar design for the murine D10 TCR, although this scTCR was fused to MBP and expressed in bacterial cytoplasm (see also Hare *et al* (1999) Nat. Struct. Biol. **6** (6): 574-81). Hilyard *et al* (1994) PNAS. **91** (19): 9057-61 report a human scTCR specific for influenza matrix protein-HLA-A2, using a V $\alpha$ -linker-V $\beta$  design and expressed in bacterial periplasm.

Chung *et al* (1994) PNAS. **91** (26) 12654-8 report the production of a human scTCR using a V $\alpha$ -linker-V $\beta$ -C $\beta$  design and expression on the surface of a mammalian cell line. This report does not include any reference to peptide-HLA specific binding of the scTCR. Plaksin *et al* (1997) J. Immunol. **158** (5): 2218-27 report a similar V $\alpha$ -linker-V $\beta$ -C $\beta$  design for producing a murine scTCR specific for an HIV gp120-H-2D<sup>d</sup> epitope. This scTCR is expressed as bacterial inclusion bodies and refolded *in vitro*.

#### *Therapeutic Use*

There is a need for targeting moieties capable of localising to cells affected by disease processes. Such targeting moieties could be utilised either to directly block the 'miss-directed' action of the immune system responsible for auto-immune disease or as a means of delivering cytotoxic agents to cancerous cells.

Ideally, molecules suitable for these applications require a specific affinity for a cell marker directly involved in the relevant disease process. Antibodies have been used for this purpose.

### *Screening Use*

A number of important cellular interactions and cell responses, including the TCR-mediated immune synapse, are controlled by contacts made between cell surface  
5 receptors and ligands presented on the surfaces of other cells. These types of specific molecular contacts are of crucial importance to the correct biochemical regulation in the human body and are therefore being studied intensely. In many cases, the objective of such studies is to devise a means of modulating cellular responses in order to prevent or combat disease.

10 Therefore, methods with which to identify compounds that bind with some degree of specificity to human receptor or ligand molecules are important as leads for the discovery and development of new disease therapeutics. In particular, compounds that interfere with certain receptor-ligand interactions have immediate potential as  
15 therapeutic agents or carriers.

Advances in combinatorial chemistry, enabling relatively easy and cost-efficient production of very large compound libraries, have increased the scope for compound testing enormously. Now the limitations of screening programmes most often reside  
20 in the nature of the assays that can be employed, the production of suitable receptor and ligand molecules and how well these assays can be adapted to high throughput screening methods.

### **Brief Description of the Invention**

25 This invention makes available a new class of alpha/beta-analogue scTCRs which are characterised by the presence of a disulfide bond between residues of the single amino acid strand, that bond contributing to the stability of the pairing between alpha and beta regions of the molecule. Such TCRs are useful for screening or therapeutic purposes.

### **Detailed Description of the Invention**

The present invention provides a single chain T cell receptor (scTCR) comprising an  $\alpha$  segment constituted by a TCR  $\alpha$  chain variable region sequence fused to the N terminus of a TCR  $\alpha$  chain constant region extracellular sequence, a  $\beta$  segment constituted by a TCR  $\beta$  chain variable region sequence fused to the N terminus of a TCR  $\beta$  chain constant region extracellular sequence, and a linker sequence linking the C terminus of the  $\alpha$  segment to the N terminus of the  $\beta$  segment, or vice versa, the constant region extracellular sequences of the  $\alpha$  and  $\beta$  segments being linked by a disulfide bond, the length of the linker sequence and the position of the disulfide bond being such that the variable region sequences of the  $\alpha$  and  $\beta$  segments are mutually orientated substantially as in native  $\alpha\beta$  T cell receptors.

In the scTCR's of the invention the requirement that the variable region sequences of the  $\alpha$  and  $\beta$  segments are mutually orientated substantially as in native  $\alpha\beta$  T cell receptors is tested by confirming that the molecule binds to a peptide-MHC complex - if it binds, then the requirement is met.

#### *$\alpha$ and $\beta$ Segments*

The constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments preferably correspond to those of a human TCR, as do the variable region sequences present in the  $\alpha$  and  $\beta$  segments. However, the correspondence between such sequences need not be 1:1 on an amino acid level. N- or C-truncation, and/or amino acid deletion and/or substitution relative to the corresponding human TCR sequences is acceptable, provided the overall result is mutual orientation of variable region sequences of the  $\alpha$  and  $\beta$  segments as in native  $\alpha\beta$  T cell receptors and retention of peptide-MHC binding functionality. In particular, because the constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments are not directly involved in contacts with the peptide-MHC complex to which the scTCR binds, they may be shorter than, or may contain substitutions or deletions relative to, extracellular constant domain sequences of native TCRs.



The constant region extracellular sequence present in the  $\alpha$  segment may include a sequence corresponding to the extracellular constant Ig domain of a TCR  $\alpha$  chain, and/or the constant region extracellular sequence present in the  $\beta$  segment may include a sequence corresponding to the extracellular constant Ig domain of a TCR  $\beta$  chain.

5

In one embodiment of the invention, the  $\alpha$  segment corresponds to substantially all the variable region of a TCR  $\alpha$  chain fused to the N terminus of substantially all the extracellular domain of the constant region of an TCR  $\alpha$  chain; and/or the  $\beta$  segment corresponds to substantially all the variable region of a TCR  $\beta$  chain fused to the N terminus of substantially all the extracellular domain of the constant region of a TCR  $\beta$  chain .

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In another embodiment, the constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to the constant regions of the  $\alpha$  and  $\beta$  chains of a native TCR truncated at their C termini such that the cysteine residues which form the native interchain disulfide bond of the TCR are excluded. Alternatively those cysteine residues may be substituted by another amino acid residue such as serine or alanine, so that the native disulfide bond is deleted. In addition, the native TCR  $\beta$  chain contains an unpaired cysteine residue and that residue may be deleted from, or replaced by a non-cysteine residue in, the  $\beta$  sequence of the scTCR of the invention.

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In one particular embodiment of the invention, the TCR  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments may together correspond to the functional variable domain of a first TCR, and the TCR  $\alpha$  and  $\beta$  chain constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments may correspond to those of a second TCR, the first and second TCRs being from the same species. Thus the  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments may correspond to those of a first human TCR, and the  $\alpha$  and  $\beta$  chain constant region extracellular sequences may correspond to those of a second human TCR. For example, A6 Tax

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scTCR constant region extracellular sequences can be used as framework onto which heterologous variable domains can be fused.

5 In another embodiment of the invention the TCR  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments together correspond to the functional variable domain of a first TCR, and the TCR  $\alpha$  and  $\beta$  chain constant region  
10 extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to those of a second TCR, the first and second TCRs being from different species. For example, other mammals including, but not limited to, mouse, rat, pig, goat and sheep. In this  
15 embodiment it is preferred that the TCR  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments together correspond to the functional variable domain of a human TCR, and the TCR  $\alpha$  and  $\beta$  chain constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to those of a murine TCR. Such  
embodiments of the present invention have the advantage that the scTCRs contain non-human constant region sequences which are likely to be immunogenic, and thus  
are likely to enhance the overall immune response to the scTCR when localised on its target cell. The immune response to aberrant cells such as cancer cells may thus be enhanced.

## 20 *Linker*

In the present invention, a linker sequence links the  $\alpha$  and  $\beta$  segments, to form a single polypeptide strand. The linker sequence may, for example, have the formula -P-AA-P- wherein P is proline and AA represents an amino acid sequence wherein the amino acids are glycine and serine.

25

For the scTCR to bind an MHC-peptide complex, the  $\alpha$  and  $\beta$  segments must be paired so that the variable region sequences thereof are orientated for such binding. Hence the linker should have sufficient length to span the distance between the C terminus of the  $\alpha$  segment and the N terminus of the  $\beta$  segment, or vice versa. On the other hand  
30 excessive linker length should preferably be avoided, in case the end of the linker at

the N-terminal variable region sequence blocks or reduces bonding of the scTCR to the target peptide-MHC complex.

For example, in the case where the constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to the constant regions of the  $\alpha$  and  $\beta$  chains of a native TCR truncated at their C termini such that the cysteine residues which form the native interchain disulfide bond of the TCR are excluded, and the linker sequence links the C terminus of the  $\alpha$  segment to the N terminus of the  $\beta$  segment, the linker may consist of from 26 to 41, for example 29, 30, 31 or 32 amino acids, and a particular linker has the formula -PGGG-(SGGGG)<sub>5</sub>-P- wherein P is proline, G is glycine and S is serine.

#### *Disulfide bond*

A principle characterising feature of the scTCRs of the present invention is the disulfide bond between the constant region extracellular sequences of the  $\alpha$  and  $\beta$  segments. That bond may correspond to the native interchain disulfide bond present in native dimeric  $\alpha\beta$  TCRs, or may have no counterpart in native TCRs, being between cysteines specifically incorporated into the constant region extracellular sequences of the  $\alpha$  and  $\beta$  segments. In some cases, both a native and a non-native disulfide bond may be desirable in the present scTCRs.

The position of the disulfide bond is subject to the requirement that the variable region sequences of the  $\alpha$  and  $\beta$  segments are mutually orientated substantially as in native  $\alpha\beta$  T cell receptors.

The disulfide bond may be formed by mutating non-cysteine residues on  $\alpha$  and  $\beta$  segments to cysteine, and causing the bond to be formed between the mutated residues. Residues whose respective  $\beta$  carbons are approximately 6 Å (0.6 nm) or less, and preferably in the range 3.5 Å (0.35 nm) to 5.9 Å (0.59 nm) apart in the native TCR are preferred, such that a disulfide bond can be formed between cysteine residues

introduced in place of the native residues. It is preferred if the disulfide bond is between residues in the constant immunoglobulin region, although it could be between residues of the membrane proximal region. Preferred sites where cysteines can be introduced to form the disulfide bond are the following residues in exon 1 of

5 TRAC\*01 for the TCR  $\alpha$  chain and TRBC1\*01 or TRBC2\*01 for the TCR  $\beta$  chain:

TCR $\alpha$ chain	TCR $\beta$ chain	Native $\beta$ carbon separation (nm)
Thr 48	Ser 57	0.473
Thr 45	Ser 77	0.533
Tyr 10	Ser 17	0.359
Thr 45	Asp 59	0.560
Ser 15	Glu 15	0.59

Now that the residues in human TCRs which can be mutated into cysteine residues to form a new interchain disulfide bond in scTCRs according to the invention have been identified, those of skill in the art will be able to mutate TCRs of other species in the same way to produce a scTCR of that species. In humans, the skilled person merely needs to look for the following motifs in the respective TCR chains to identify the residue to be mutated (the shaded residue is the residue for mutation to a cysteine).

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$\alpha$  Chain Thr 48: DSDVYITDKTVLDMRSMDFK (amino acids 39-58 of exon 1 of the TRAC\*01 gene)

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$\alpha$  Chain Thr 45: QSKDSDVYITDKTVLDMRSM(amino acids 36-55 of exon 1 of the TRAC\*01 gene)

$\alpha$  Chain Tyr 10: DIQNPDPAVYQLRDSKSSDK(amino acids 1-20 of exon 1 of the TRAC\*01 gene)

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$\alpha$  Chain Ser 15: DPAVYQLRDSKSSDKSVCLF(amino acids 6-25 of exon 1 of the TRAC\*01 gene)

β Chain Ser 57: NGKEVHSGVSTDPQPLKEQP(amino acids 48- 67 of exon 1  
of the TRBC1\*01 & TRBC2\*01 genes)

5 β Chain Ser 77: ALNDSRYALSSRLRVSATFW(amino acids 68- 87 of exon 1  
of the TRBC1\*01 & TRBC2\*01 genes)

β Chain Ser 17: PPEVAVFEPSEAEISHTQKA(amino acids 8- 27 of exon 1 of  
the TRBC1\*01 & TRBC2\*01 genes)

10 β Chain Asp 59: KEVHSGVSTDPQPLKEQPAL(amino acids 50- 69 of exon 1  
of the TRBC1\*01 & TRBC2\*01 genes)

β Chain Glu 15: VFPPEVAVFPSEAEISHTQ(amino acids 6- 25 of exon 1 of  
the TRBC1\*01 & TRBC2\*01 genes)

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In other species, the TCR chains may not have a region which has 100% identity to the  
above motifs. However, those of skill in the art will be able to use the above motifs to  
identify the equivalent part of the TCR α or β chain and hence the residue to be  
mutated to cysteine. Alignment techniques may be used in this respect. For example,  
20 ClustalW, available on the European Bioinformatics Institute website  
(<http://www.ebi.ac.uk/index.html>) can be used to compare the motifs above to a  
particular TCR chain sequence in order to locate the relevant part of the TCR sequence  
for mutation.

25 The present invention includes within its scope αβ-analogue scTCRs, as well as those  
of other mammals, including, but not limited to, mouse, rat, pig, goat and sheep. Also  
included are human/non-human chimeric scTCRs as discussed above. As mentioned  
above, those of skill in the art will be able to determine sites equivalent to the above-  
described human sites at which cysteine residues can be introduced to form an inter-  
30 chain disulfide bond. For example, the following shows the amino acid sequences of  
the mouse Cα and Cβ soluble domains, together with motifs showing the murine

residues equivalent to the human residues mentioned above that can be mutated to cysteines to form a TCR interchain disulfide bond (where the relevant residues are shaded):

5 Mouse C $\alpha$  soluble domain:

PYIQNPEPAVYQLKDPRSQDSTLCLFTDFDSQINVPKTMESGTFITDKTVLDMK  
AMDSKSNGAIAWSNQTSFTCQDIFKETNATYPSSDVP

Mouse C $\beta$  soluble domain:

10 EDLRNVTTPPKVSLFEPSKAEIANKQKATLVCLARGFFPDHVELSWVNGREV  
HSGVSTDPQAYKESNYSYCLSSRLRVSATFWHNPRNHFRQCQVQFHGLSEEDK  
WPEGSPKPVTQNISAEAWGRAD

15 Murine equivalent of human  $\alpha$  Chain Thr 48: ESGTFTDKTVLDMKAMDSK

Murine equivalent of human  $\alpha$  Chain Thr 45: KTMESGTFITDKTVLDMKAM

Murine equivalent of human  $\alpha$  Chain Tyr 10: YIQNPEPAVYQLKDPRSQDS

20 Murine equivalent of human  $\alpha$  Chain Ser 15: AVYQLKDPRSQDSTLCLFTD

Murine equivalent of human  $\beta$  Chain Ser 57: NGREVVHSGVSTDPQAYKESN

Murine equivalent of human  $\beta$  Chain Ser 77: KESNYSYCLSSRLRVSATFW

25 Murine equivalent of human  $\beta$  Chain Ser 17: PPKVSLFEPSKAEIANKQKA

Murine equivalent of human  $\beta$  Chain Asp 59: REVHSGVSTDPQAYKESNYS

30 Murine equivalent of human  $\beta$  Chain Glu 15: VTPPKVSLFEPSKAEIANKQ

As discussed above, the A6 Tax sTCR extracellular constant regions can be used as framework onto which heterologous variable domains can be fused. It is preferred that the heterologous variable region sequences are linked to the constant region sequences at any point between the introduced disulfide bond and the N termini of the constant region sequences. In the case of the A6 Tax TCR  $\alpha$  and  $\beta$  constant region sequences, the disulfide bond may be formed between cysteine residues introduced at amino acid residues 158 and 172 respectively. Therefore it is preferred if the heterologous  $\alpha$  and  $\beta$  chain variable region sequence attachment points are between residues 159 or 173 and the N terminus of the  $\alpha$  or  $\beta$  constant region sequences respectively.

In order to produce the chimeric human/murine TCRs discussed above it is again preferred that the heterologous (human) variable region sequences are linked to the (murine) constant region sequences at any point between the introduced disulfide bond and the N termini of the constant region sequences.

#### *Additional Aspects*

A scTCR (which is preferably human) of the present invention may be provided in substantially pure form, or as a purified or isolated preparation. For example, it may be provided in a form which is substantially free of other proteins.

A plurality of scTCRs of the present invention may be provided in a multivalent complex. Thus, the present invention provides, in one aspect, a multivalent T cell receptor (TCR) complex, which comprises a plurality of soluble T cell receptors as described herein. Each of the plurality of soluble TCRs is preferably identical.

In a further aspect, the invention provides a method for detecting MHC-peptide complexes, which comprises:

- a. providing a scTCR of the current invention
- b. contacting the scTCR with the MHC-peptide complexes; and detecting binding of the scTCR to the MHC-peptide complexes.

### *Therapeutic Use*

The scTCR (or multivalent complex thereof) of the present invention may alternatively or additionally be associated with (e.g. covalently or otherwise linked to) a therapeutic agent which may be, for example, a toxic moiety for use in cell killing, or an immunostimulating agent such as an interleukin or a cytokine. A multivalent scTCR complex of the present invention may have enhanced binding capability for a pMHC compared to a non-multimeric T cell receptor heterodimer. Thus, the multivalent scTCR complexes according to the invention are particularly useful for tracking or targeting cells presenting particular antigens *in vitro* or *in vivo*, and are also useful as intermediates for the production of further multivalent TCR complexes having such uses. The scTCR or multivalent scTCR complex may therefore be provided in a pharmaceutically acceptable formulation for use *in vivo*.

The invention also provides a method for delivering a therapeutic agent to a target cell, which method comprises contacting potential target cells with a scTCR or multivalent scTCR complex in accordance with the invention under conditions to allow attachment of the scTCR or multivalent scTCR complex to the target cell, said scTCR or multivalent scTCR complex being specific for the MHC-peptide complexes and having the therapeutic agent associated therewith.

In particular, the soluble scTCR or multivalent scTCR complex can be used to deliver therapeutic agents to the location of cells presenting a particular antigen. This would be useful in many situations and, in particular, against tumours. A therapeutic agent could be delivered such that it would exercise its effect locally but not only on the cell it binds to. Thus, one particular strategy envisages anti-tumour molecules linked to T cell receptors or multivalent scTCR complexes specific for tumour antigens.

Many therapeutic agents could be employed for this use, for instance radioactive compounds, enzymes (perforin for example) or chemotherapeutic agents (cis-platin for example). To ensure that toxic effects are exercised in the desired location the toxin



could be inside a liposome linked to streptavidin so that the compound is released slowly. This will prevent damaging effects during the transport in the body and ensure that the toxin has maximum effect after binding of the scTCR to the relevant antigen presenting cells.

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Other suitable therapeutic agents include:

- small molecule cytotoxic agents, i.e. compounds with the ability to kill mammalian cells having a molecular weight of less than 700 daltons. Such compounds could also contain toxic metals capable of having a cytotoxic effect.  
10 Furthermore, it is to be understood that these small molecule cytotoxic agents also include pro-drugs, i.e. compounds that decay or are converted under physiological conditions to release cytotoxic agents. Examples of such agents include cis-platin, maytansine derivatives, rachelmycin, calicheamicin, docetaxel, etoposide, gemcitabine, ifosfamide, irinotecan, melphalan, mitoxantrone, sorfimer  
15 sodiumphotofrin II, temozolmide, topotecan, trimetreate glucuronate, auristatin E vincristine and doxorubicin;
- peptide cytotoxins, i.e. proteins or fragments thereof with the ability to kill mammalian cells. Examples include ricin, diphtheria toxin, pseudomonas bacterial exotoxin A, DNAase and RNAase;
- 20 • radio-nuclides, i.e. unstable isotopes of elements which decay with the concurrent emission of one or more of  $\alpha$  or  $\beta$  particles, or  $\gamma$  rays. Examples include iodine 131, rhenium 186, indium 111, yttrium 90, bismuth 210 and 213, actinium 225 and astatine 213;
- prodrugs, such as antibody directed enzyme pro-drugs;
- 25 • immuno-stimulants, i.e. moieties which stimulate immune response. Examples include cytokines such as IL-2, chemokines such as IL-8, platelet factor 4, melanoma growth stimulatory protein, etc, antibodies or fragments thereof, complement activators, xenogeneic protein domains, allogeneic protein domains, viral/bacterial protein domains and viral/bacterial peptides.

30

Soluble scTCRs or multivalent scTCR complexes of the invention may be linked to an enzyme capable of converting a prodrug to a drug. This allows the prodrug to be converted to the drug only at the site where it is required (i.e. targeted by the scTCR).

5 Examples of suitable MHC-peptide targets for the scTCR according to the invention include, but are not limited to, viral epitopes such as HTLV-1 epitopes (e.g. the Tax peptide restricted by HLA-A2; HTLV-1 is associated with leukaemia), HIV epitopes, EBV epitopes, CMV epitopes; melanoma epitopes (e.g. MAGE-1 HLA-A1 restricted  
10 antigen G250 restricted by HLA-A2); and epitopes associated with autoimmune disorders, such as rheumatoid arthritis. Further disease-associated pMHC targets, suitable for use in the present invention, are listed in the HLA Factbook (Barclay (Ed) Academic Press), and many others are being identified.

15 Localising drug delivery through the specificity of scTCRs can potentially enhance a multitude of disease treatments.

Viral diseases for which drugs exist, e.g. HIV, SIV, EBV, CMV, would benefit from the drug being released or activated in the near vicinity of infected cells. For cancer,  
20 the localisation in the vicinity of tumours or metastasis would enhance the effect of toxins or immunostimulants. In autoimmune diseases, immunosuppressive drugs could be released slowly, having more local effect over a longer time-span while minimally affecting the overall immuno-capacity of the subject. In the prevention of graft rejection, the effect of immunosuppressive drugs could be optimised in the same  
25 way. For vaccine delivery, the vaccine antigen could be localised in the vicinity of antigen presenting cells, thus enhancing the efficacy of the antigen. The method can also be applied for imaging purposes.

The scTCRs of the present invention may be used to modulate T cell activation by  
30 binding to specific pMHC and thereby inhibiting T cell activation. Autoimmune diseases involving T cell-mediated inflammation and/or tissue damage would be amenable to this

approach, for example type I diabetes. Knowledge of the specific peptide epitope presented by the relevant pMHC is required for this use.

5 Medicaments in accordance with the invention will usually be supplied as part of a sterile, pharmaceutical composition which will normally include a pharmaceutically acceptable carrier. This pharmaceutical composition may be in any suitable form, (depending upon the desired method of administering it to a patient). It may be provided in unit dosage form, will generally be provided in a sealed container and may be provided as part of a kit. Such a kit would normally (although not necessarily) include instructions  
10 for use. It may include a plurality of said unit dosage forms.

The pharmaceutical composition may be adapted for administration by any appropriate route, for example by the oral (including buccal or sublingual), rectal, nasal, topical (including buccal, sublingual or transdermal), vaginal or parenteral (including  
15 subcutaneous, intramuscular, intravenous or intradermal) route. Such compositions may be prepared by any method known in the art of pharmacy, for example by admixing the active ingredient with the carrier(s) or excipient(s) under sterile conditions.

#### *Screening Use*

20 The scTCRs of the present invention are capable of utilisation in screening methods designed to identify modulators, including inhibitors, of the TCR-mediated cellular immune synapse.

As is know to those skilled in the art there are a number of assay formats that provide  
25 a suitable basis for protein-protein interaction screens of this type.

Amplified Luminescent Proximity Homogeneous Assay systems such as the AlphaScreen™, rely on the use of "Donor" and "Acceptor" beads that are coated with a layer of hydrogel to which receptor and ligand proteins can be attached. The  
30 interaction between these receptor and ligand molecules brings the beads into proximity. When these beads are subject to laser light a photosensitizer in the "Donor"

bead converts ambient oxygen to a more excited singlet state. The singlet state oxygen molecules diffuse across to react with a chemiluminescer in the "Acceptor" bead that further activates fluorophores contained within the same bead. The fluorophores subsequently emit light at 520-620 nm, this signals that the receptor-ligand interaction has occurred. The presence of an inhibitor of the receptor-ligand interaction causes this signal to be diminished.

Surface Plasmon Resonance (SPR) is an interfacial optical assay, in which one binding partner (normally the receptor) is immobilised on a 'chip' (the sensor surface) and the binding of the other binding partner (normally the ligand), which is soluble and is caused to flow over the chip, is detected. The binding of the ligand results in an increase in concentration of protein near to the chip surface which causes a change in the refractive index in that region. The surface of the chip is comprised such that the change in refractive index may be detected by surface plasmon resonance, an optical phenomenon whereby light at a certain angle of incidence on a thin metal film produces a reflected beam of reduced intensity due to the resonant excitation of waves of oscillating surface charge density (surface plasmons). The resonance is very sensitive to changes in the refractive index on the far side of the metal film, and it is this signal which is used to detect binding between the immobilised and soluble proteins. Systems which allow convenient use of SPR detection of molecular interactions, and data analysis, are commercially available. Examples are the Iasys™ machines (Fisons) and the Biacore™ machines.

Other interfacial optical assays include total internal reflectance fluorescence (TIRF), resonant mirror (RM) and optical grating coupler sensor (GCS), and are discussed in more detail in Woodbury and Venton (*J. Chromatog. B.* **725** 113-137 (1999)). The scintillation proximity assay (SPA) has been used to screen compound libraries for inhibitors of the low affinity interaction between CD28 and B7 ( $K_d$  probably in the region of 4  $\mu$ M (Van der Merwe *et al J. Exp. Med.* **185**:393-403 (1997), Jenh *et al, Anal Biochem* **165**(2) 287-93 (1998)). SPA is a radioactive assay making use of beta particle emission from certain radioactive isotopes which transfers energy to a

scintillant immobilised on the indicator surface. The short range of the beta particles in solution ensures that scintillation only occurs when the beta particles are emitted in close proximity to the scintillant. When applied for the detection of protein-protein interactions, one interaction partner is labelled with the radioisotope, while the other is  
5 either bound to beads containing scintillant or coated on a surface together with scintillant. If the assay can be set up optimally, the radioisotope will be brought close enough to the scintillant for photon emission to be activated only when binding between the two proteins occurs.

10 A further aspect of the invention is a method of identifying an inhibitor of the interaction between an scTCR and a MHC-peptide complex comprising contacting the scTCR with a MHC-peptide binding partner, in the presence of and in the absence of a test compound, and determining whether the presence of the test compound reduces binding of the scTCR to the MHC-peptide complex, such reduction being taken as  
15 identifying an inhibitor.

A final aspect of the invention is a method of identifying a potential inhibitor of the interaction between an scTCR and a MHC-peptide complex comprising contacting the scTCR or MHC-peptide binding partner with a test compound and determining  
20 whether the test compound binds to the scTCR and/or the MHC-peptide complex, such binding being taken as identifying a potential inhibitor. This aspect of the invention may find particular utility in interfacial optical assays such as those carried out using the BIAcore™ system.

25 Preferred features of each aspect of the invention are as for each of the other aspects *mutatis mutandis*. The prior art documents mentioned herein are incorporated to the fullest extent permitted by law.

30

### Examples

The invention is further described in the following examples, which do not limit the scope of the invention in any way.

5      Reference is made in the following to the accompanying drawings in which:

Figures 1a and 1b show respectively the nucleic acid sequences of the  $\alpha$  and  $\beta$  chains of a soluble A6 TCR, mutated so as to introduce a cysteine codon. The shading indicates the introduced cysteine codons;

10

Figure 2a shows the A6 TCR  $\alpha$  chain extracellular amino acid sequence, including the T<sub>48</sub>  $\rightarrow$  C mutation (underlined) used to produce the novel disulphide inter-chain bond, and Figure 2b shows the A6 TCR  $\beta$  chain extracellular amino acid sequence, including the S<sub>57</sub>  $\rightarrow$  C mutation (underlined) used to produce the novel disulphide inter-chain bond;

15

Figure 3 shows the DNA and amino acid sequence of the Gly/Ser linker (30mer)

Figure 4 summarises the cloning strategy used to produce the scDiS A6 TCR

20

Figure 5a shows the DNA sequence of the scDiS A6 TCR.

Figure 5b shows the amino acid sequence of the scDiS A6 TCR.

25      Figure 6 illustrates the elution of the scDiS A6 TCR protein from a POROS 50HQ ion exchange column using a 0-500 mM NaCl gradient, as indicated by the straight line;

Figure 7 shows the results of both reducing SDS-PAGE (Coomassie-stained) and non-reducing SDS-PAGE (Coomassie-stained) gels of fractions A15, B10, B9 and B3 from the column run illustrated by Figure 6. Fractions B9 and B10 clearly contain protein corresponding to the expected size of the scDiS A6 TCR;

30

Figure 8 illustrates the elution of the scDiS A6 TCR elution from a Superdex 200 gel filtration column of fractions B10-B7 from the ion exchange column run shown in Figure 6;

5

Figure 9 shows the results of both reducing SDS-PAGE (Coomassie-stained) and non-reducing SDS-PAGE (Coomassie-stained) gels of fractions B8, B7, B3 and B2 from the gel filtration column run illustrated by Figure 8. Fraction B7 clearly contains protein corresponding to the expected size of the scDiS A6 TCR;

10

Figure 10 is a final gel filtration run into BIAcore buffer of the concentrated fractions B9-B6 of the gel filtration run shown in Figure 8. The scDiS A6 TCR elutes as a single major peak;

15

Figure 11 BIAcore data for binding of the scDiS A6 TCR to HLA-A2 TAX;

*Example 1 – Design of primers and mutagenesis of A6 Tax TCR  $\alpha$  and  $\beta$  chains to introduce the cysteine residues required for the formation of a novel inter-chain disulphide bond*

- 5 For mutating A6 Tax threonine 48 of exon 1 in TRAC\*01 to cysteine, the following primers were designed (mutation shown in lower case):

5'-C ACA GAC AAA tgT GTG CTA GAC AT

5'-AT GTC TAG CAC Aca TTT GTC TGT G

10

For mutating A6 Tax serine 57 of exon 1 in both TRBC1\*01 and TRBC2\*01 to cysteine, the following primers were designed (mutation shown in lower case):

5'-C AGT GGG GTC tGC ACA GAC CC

15 5'-GG GTC TGT GCa GAC CCC ACT G

*PCR mutagenesis:*

Expression plasmids containing the genes for the A6 Tax TCR  $\alpha$  or  $\beta$  chain were mutated using the  $\alpha$ -chain primers or the  $\beta$ -chain primers respectively, as follows.

- 20 100 ng of plasmid was mixed with 5  $\mu$ l 10 mM dNTP, 25  $\mu$ l 10xPfu-buffer (Stratagene), 10 units Pfu polymerase (Stratagene) and the final volume was adjusted to 240  $\mu$ l with H<sub>2</sub>O. 48  $\mu$ l of this mix was supplemented with primers diluted to give a final concentration of 0.2  $\mu$ M in 50  $\mu$ l final reaction volume. After an initial denaturation step of 30 seconds at 95°C, the reaction mixture was subjected to 15
- 25 rounds of denaturation (95°C, 30 sec.), annealing (55°C, 60 sec.), and elongation (73°C, 8 min.) in a Hybaid PCR express PCR machine. The product was then digested for 5 hours at 37°C with 10 units of DpnI restriction enzyme (New England Biolabs). 10  $\mu$ l of the digested reaction was transformed into competent XL1-Blue bacteria and grown for 18 hours at 37°C. A single colony was picked and grown over night in 5 ml
- 30 TYP + ampicillin (16 g/l Bacto-Tryptone, 16 g/l Yeast Extract, 5 g/l NaCl, 2.5 g/l



K<sub>2</sub>HPO<sub>4</sub>, 100 mg/l Ampicillin). Plasmid DNA was purified on a Qiagen mini-prep column according to the manufacturer's instructions and the sequence was verified by automated sequencing at the sequencing facility of Department of Biochemistry, Oxford University. The respective mutated nucleic acid and amino acid sequences are  
5 shown in Figures 1a and 2a for the  $\alpha$  chain and Figures 1b and 2b for the  $\beta$  chain.

*Example 2 – Design, Expression and testing of a single-chain A6 TCR incorporating a novel disulphide inter-chain bond.*

The expression vectors containing the DNA sequences of the mutated A6 TCR  $\alpha$  and  $\beta$  chains incorporating the additional cysteine residues required for the formation of a novel disulphide prepared in Example 1 and as shown in figures 1a and 1b were used as the basis for the production of a single-chain A6 TCR, with the exception that the stop codon (TAA) was removed from the end of the  $\alpha$  chain sequence, as follows:

The scDiS A6 TCR contains a 30 amino acid linker sequence between the C-terminus of the TCR  $\alpha$  chain and the N-terminus of the  $\beta$  chain. Figure 3 shows the DNA and amino acid sequence of this linker. The cloning strategy employed to produce the scDiS A6 TCR is summarised in Figure 4.

Briefly, the alpha and beta chains of the A6 dsTCR were amplified by PCR using primers containing restriction sites as shown in figure 4, ie.:

Alpha 5' primer: ccaaggccatatgcagaaggaagtggagcagaactct

Alpha 3' primer: ttgggcccgcggatccgccccgggggaactttctgggctgggg

Beta 5' primer: tccccgggggcggatccggcgggcccacgctggtgtcactcag

Beta 3' primer: gggaagcttagtctgctctaccccaggcctcg

The Two fragments thus generated were PCR stitched using the 5' alpha and 3' beta primers to give a single-chain TCR with a short linker containing the sites XmaI-BamHI-ApaI. This fragment was cloned into pGMT7. The full length linker was then inserted in two stages, firstly a 42bp fragment was inserted using the XmaI and BamHI sites:

5'-CC GGG GGT GGC TCT GGC GGT GGC GGT TCA GGC GGT GGC G -3'  
3'- C CCA CCG AGA CCG CCA CCG CCA AGT CCG CCA CCG CCT AG-5'

Secondly, a 48bp fragment was inserted using the BamHI and ApaI sites to create a 90bp linker between the 3' end of the alpha chain and the 5' end of the beta chain. The 48bp fragment was made by PCR extension of a mixture of the following oligos:

5

```
5' - GC GGA TCC GGC GGT GGC GGT TCG GGT GGC GGT GGC TC -3'
3' - CCA AGC CCA CCG CCA CCG AGT CCG CCA CCG CCC GGG TG -5'
```

10

The product of this extension was digested with BamHI and ApaI and ligated into the digested plasmid containing the 42bp linker fragment.

The complete DNA and amino acid sequence of the scDiS A6 TCR is shown in Figures 5a and 5b respectively.

15

*Expression and Purification of single-chain disulphide linked A6 TCR:*

20

The expression plasmid containing the single-chain disulphide linked A6 TCR was transformed into *E.coli* strain BL21pLysS, and single ampicillin-resistant colonies were grown at 37°C in TYP (ampicillin 100µg/ml) medium to OD<sub>600</sub> of 0.4 before inducing protein expression with 0.5mM IPTG. Cells were harvested three hours post-induction by centrifugation for 30 minutes at 4000rpm in a Beckman J-6B. Cell pellets were re-suspended in a buffer containing 50mM Tris-HCl, 25% (w/v) sucrose, 1mM NaEDTA, 0.1% (w/v) NaAzide, 10mM DTT, pH 8.0. After an overnight freeze-thaw step, re-suspended cells were sonicated in 1 minute bursts for a total of around 10 minutes in a Milsonix XL2020 sonicator using a standard 12mm diameter probe.

25

Inclusion body pellets were recovered by centrifugation for 30 minutes at 13000rpm in a Beckman J2-21 centrifuge. Three detergent washes were then carried out to remove cell debris and membrane components. Each time the inclusion body pellet was homogenised in a Triton buffer (50mM Tris-HCl, 0.5% Triton-X100, 200mM NaCl, 10mM NaEDTA, 0.1% (w/v) NaAzide, 2mM DTT, pH 8.0) before being pelleted by centrifugation for 15 minutes at 13000rpm in a Beckman J2-21. Detergent and salt was then removed by a similar wash in the following buffer: 50mM Tris-HCl, 1mM NaEDTA, 0.1% (w/v) NaAzide, 2mM DTT, pH 8.0. Finally, the inclusion bodies were divided into 30 mg aliquots and frozen at -70°C. Inclusion body protein yield

30

was quantitated by solubilising with 6M guanidine-HCl and measurement with a Bradford dye-binding assay (PerBio).

5 Approximately 15mg of the solubilised inclusion body chain was thawed from frozen stocks. The inclusion bodies were diluted to a final concentration of 5mg/ml in 6M guanidine solution, and DTT (2M stock) was added to a final concentration of 10mM. The mixture was incubated at 37°C for 30 min. 1 litre of the following refolding buffer: 100mM Tris pH 8.5, 400mM L-Arginine, 2mM EDTA, 5mM reduced Glutathione, 0.5mM oxidised Glutathione, 5M urea, 0.2mM PMSF was prepared and  
10 stirred vigoursly at 5°C ± 3°C. The redox couple (2-mercaptoethylamine and cystamine (to final concentrations of 6.6mM and 3.7mM, respectively) were added approximately 5 minutes before addition of the denatured TCR chains. The protein was then allowed to refold for approximately 5 hours ± 15 minutes with stirring at 5°C ± 3°C. The refold was then dialysed twice, firstly against 10 litres of 100mM urea,  
15 secondly against 10 litres of 100mM urea, 10mM Tris pH 8.0. Both refolding and dialysis steps were carried out at 6-8°C.

scTCR was separated from degradation products and impurities by loading the dialysed refold onto a POROS 50HQ anion exchange column and eluting bound  
20 protein with a gradient of 0-500mM NaCl over 50 column volumes using an Akta purifier (Pharmacia) as in Figure 6. Peak fractions were stored at 4°C and analysed by Coomassie-stained SDS-PAGE (Figure 7) before being pooled and concentrated. The sTCR was then purified and characterised using a Superdex 200HR gel filtration column (Figure 8) pre-equilibrated in HBS-EP buffer (10 mM HEPES pH 7.4, 150  
25 mM NaCl, 3.5 mM EDTA, 0.05% nonidet p40). Peak fractions were stored at 4°C and analysed by Coomassie-stained SDS-PAGE (Figure 9) before being pooled and concentrated. Finally, concentrated fractions B9-B6 were run put through another gel filtration step in order to produce purified protein in BIAcore buffer, (Figure 10) The peak eluting at a relative molecular weight of approximately 50 kDa was pooled. This  
30 was concentrated prior to characterisation by BIAcore surface plasmon resonance analysis.

*Example 3 - BIAcore surface plasmon resonance characterisation of scTCR binding to HLA-A2 Tax*

5 A surface plasmon resonance biosensor (BIAcore 3000™) was used to analyse the binding of the A6 scTCR to its peptide-MHC ligand (HLA-A2 Tax). This was facilitated by producing single pMHC complexes (described below) which were immobilised to a streptavidin-coated binding surface in a semi-oriented fashion, allowing efficient testing of the binding of a soluble T-cell receptor to up to four different pMHC (immobilised on separate flow cells) simultaneously. Manual  
10 injection of HLA complex allows the precise level of immobilised class I molecules to be manipulated easily.

Such immobilised complexes are capable of binding both T-cell receptors and the coreceptor CD8 $\alpha\alpha$ , both of which may be injected in the soluble phase.

15 Biotinylated class I HLA-A2 - Tax complexes were refolded *in vitro* from bacterially-expressed inclusion bodies containing the constituent subunit proteins and synthetic peptide, followed by purification and *in vitro* enzymatic biotinylation (O'Callaghan *et al.* (1999) *Anal. Biochem.* 266: 9-15). HLA-heavy chain was expressed with a C-terminal biotinylation tag which replaces the transmembrane and cytoplasmic domains  
20 of the protein in an appropriate construct. The HLA light-chain or  $\beta$ 2-microglobulin was also expressed as inclusion bodies in *E.coli* from an appropriate construct, at a level of ~500 mg/litre bacterial culture.

25 *E. coli* cells were lysed and inclusion bodies are purified to approximately 80% purity. Protein from inclusion bodies was denatured in 6 M guanidine-HCl, 50 mM Tris pH 8.1, 100 mM NaCl, 10 mM DTT, 10 mM EDTA, and was refolded at a concentration of 30 mg/litre heavy chain, 30 mg/litre  $\beta$ 2m into 0.4 M L-Arginine-HCl, 100 mM Tris pH 8.1, 3.7 mM cystamine, mM cysteamine, 4 mg/ml peptide (e.g. tax 11-19), by  
30 addition of a single pulse of denatured protein into refold buffer at < 5°C. Refolding was allowed to reach completion at 4°C for at least 1 hour.

Buffer was exchanged by dialysis in 10 volumes of 10 mM Tris pH 8.1. Two changes of buffer were necessary to reduce the ionic strength of the solution sufficiently. The protein solution was then filtered through a 1.5µm cellulose acetate filter and loaded  
5 onto a POROS 50HQ anion exchange column (8 ml bed volume). Protein was eluted with a linear 0-500 mM NaCl gradient. HLA-A2-peptide complex eluted at approximately 250 mM NaCl, and peak fractions were collected, a cocktail of protease inhibitors (Calbiochem) was added and the fractions were chilled on ice.

10 Biotinylation tagged HLA complexes were buffer exchanged into 10 mM Tris pH 8.1, 5 mM NaCl using a Pharmacia fast desalting column equilibrated in the same buffer. Immediately upon elution, the protein-containing fractions were chilled on ice and protease inhibitor cocktail (Calbiochem) was added. Biotinylation reagents were then added: 1 mM biotin, 5 mM ATP (buffered to pH 8), 7.5 mM MgCl<sub>2</sub>, and 5 µg/ml  
15 BirA enzyme (purified according to O'Callaghan *et al.* (1999) *Anal. Biochem.* **266**: 9-15). The mixture was then allowed to incubate at room temperature overnight.

Biotinylated HLA complexes were purified using gel filtration chromatography. A Pharmacia Superdex 75 HR 10/30 column was pre-equilibrated with filtered PBS and  
20 1 ml of the biotinylation reaction mixture was loaded and the column was developed with PBS at 0.5 ml/min. Biotinylated HLA complexes eluted as a single peak at approximately 15 ml. Fractions containing protein were pooled, chilled on ice, and protease inhibitor cocktail was added. Protein concentration was determined using a Coomassie-binding assay (PerBio) and aliquots of biotinylated HLA complexes were  
25 stored frozen at -20°C. Streptavidin was immobilised by standard amine coupling methods.

The interactions between A6 Tax scTCR containing a novel inter-chain bond and its ligand/ MHC complex or an irrelevant HLA-peptide combination, the production of  
30 which is described above, were analysed on a BIAcore 3000™ surface plasmon resonance (SPR) biosensor. SPR measures changes in refractive index expressed in

response units (RU) near a sensor surface within a small flow cell, a principle that can be used to detect receptor ligand interactions and to analyse their affinity and kinetic parameters. The probe flow cells were prepared by immobilising the individual HLA-peptide complexes in separate flow cells via binding between the biotin cross linked onto  $\beta 2m$  and streptavidin which have been chemically cross linked to the activated surface of the flow cells. The assay was then performed by passing scTCR over the surfaces of the different flow cells at a constant flow rate, measuring the SPR response in doing so. Injections of soluble sTCR at constant flow rate and different concentrations over the peptide-HLA complex were used to define the background resonance. The values of these control measurements were subtracted from the values obtained with specific peptide-HLA complex and used to calculate binding affinities expressed as the dissociation constant,  $K_d$  (Price & Dwek, Principles and Problems in Physical Chemistry for Biochemists (2<sup>nd</sup> Edition) 1979, Clarendon Press, Oxford).

15 The BIAcore analysis of the scDiS A6 TCR demonstrated that this molecule bound specifically to its cognate ligand (HLA-A2 TAX) with a  $k_d$  of  $12.4 \pm 1.62 \mu M$ .

Claims:

1. A single chain T cell receptor (scTCR) comprising

5 an  $\alpha$  segment constituted by a TCR  $\alpha$  chain variable region sequence fused to the N terminus of a TCR  $\alpha$  chain constant region extracellular sequence ,

a  $\beta$  segment constituted by a TCR  $\beta$  chain variable region fused to the N terminus of a TCR  $\beta$  chain constant region extracellular sequence sequence, and

10 a linker sequence linking the C terminus of the  $\alpha$  segment to the N terminus of the  $\beta$  segment, or vice versa,

15 the constant region extracellular sequences of the  $\alpha$  and  $\beta$  segments being linked by a disulfide bond,

the length of the linker sequence and the position of the disulfide bond being such that the variable region sequences of the  $\alpha$  and  $\beta$  segments are mutually orientated substantially as in native  $\alpha\beta$  T cell receptors.

20 2. A scTCR as claimed in claim 1 wherein a disulfide bond linking constant region extracellular sequences of the  $\alpha$  and  $\beta$  segments is one which has no equivalent in native  $\alpha\beta$  T cell receptors.

25 3. A scTCR as claimed in claim 1 or claim 2 wherein a disulfide bond links amino acid residues in sub-sequences of the  $\alpha$  and  $\beta$  segments corresponding to sequences present in the extracellular constant Ig domains of TCR  $\alpha$  and  $\beta$  chains.

30 4. A scTCR as claimed in claim 3 wherein the disulfide bond links cysteine residues substituted for amino acid residues whose  $\beta$  carbon atoms are less than 0.6



nm apart in corresponding sequences of the extracellular constant Ig domains of TCR  $\alpha$  and  $\beta$  chains

5. A scTCR as claimed in claim 3 or claim 4 wherein the constant region  
5 extracellular sequence present in the  $\alpha$  segment includes a sequence corresponding to the extracellular constant Ig domain of a TCR  $\alpha$  chain, and/or the constant region extracellular sequence present in the  $\beta$  segments includes a sequence corresponding to the extracellular constant Ig domain of a TCR  $\beta$  chain.
- 10 6. A scTCR as claimed in any of the preceding claims wherein (a) the  $\alpha$  segment is the variable region of a TCR fused to the N terminus of the extracellular domain of the  $\alpha$  chain constant region of a TCR  $\alpha$  chain; and/or (b) the  $\beta$  segment is the variable region of a TCR  $\beta$  chain fused to the N terminus of the extracellular domain of the constant region of a TCR  $\beta$  chain.
- 15 7. A scTCR as claimed in any of claims 1 to 5 wherein the constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to the constant regions of the  $\alpha$  and  $\beta$  chains of a native TCR truncated at their C termini such that the cysteine residues which form the native interchain disulfide bond of the TCR are  
20 excluded.
8. A scTCR as claimed in any of claims 1 to 5 wherein the constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to the constant regions of the  $\alpha$  and  $\beta$  chains of a native TCR in which cysteine residues which form  
25 the native interchain disulfide bond are substituted by another amino acid residue.
9. A scTCR as claimed in claim 8, wherein the said cysteine residues are substituted by serine or alanine.

10. A scTCR as claimed in any of the preceding claims wherein the linker sequence has the formula -P-AA-P- wherein P is proline and AA represents an amino acid sequence wherein the amino acids are glycine and serine.

5 11. A scTCR as claimed in any of the preceding claims wherein the linker sequence links the C terminus of the  $\alpha$  domain to the N terminus of the  $\beta$  domain.

12. A scTCR as claimed in claim 11 wherein the linker sequence consists of from 26 to 41 amino acids.

10 13. A scTCR as claimed in claim 11 wherein the linker sequence consists of 29, 30, 31 or 32 amino acids.

14. A scTCR as claimed in claim 11 wherein the linker sequence consists of 33, 34, 35 or 36 amino acids.

15 15. A scTCR as claimed in claim 11 wherein the linker sequence is -PGGG-(SGGGG)<sub>5</sub>-P- wherein P is proline, G is glycine and S is serine.

20 16. A scTCR as claimed in claim 11 wherein the linker sequence is -PGGG-(SGGGG)<sub>6</sub>-P- wherein P is proline, G is glycine and S is serine.

17. A sTCR as claimed in any of the preceding claims in which an unpaired cysteine residue present in native TCR  $\beta$  chain is not present.

25 18. A scTCR as claimed in any preceding claim, wherein the constant region extracellular sequence of the  $\alpha$  segment includes a sequence corresponding corresponds to TRAC\*01 and the  $\beta$  segment includes a sequence corresponding to TRBC1\*01 or TRBC2\*01, and the said non-native disulfide bond is between cysteine residues substituted for Thr 48 of exon 1 of TRAC\*01 and Ser 57 of exon 1 of TRBC1\*01 or TRBC2\*01.

30

19. A scTCR as claimed in any one of claims 1 to 18, wherein a disulfide bond links cysteine residues substituted for Thr 45 of exon 1 of TRAC\*01 and Ser 77 of exon 1 of TRBC1\*01 or TRBC2\*01.
- 5
20. A scTCR as claimed in any one of claims 1 to 18, wherein a disulfide bond links cysteine residues substituted for Tyr 10 of exon 1 of TRAC\*01 and Ser 17 of exon 1 of TRBC1\*01 or TRBC2\*01.
- 10
21. A scTCR as claimed in any one of claims 1 to 18, wherein a disulfide bond links cysteine residues substituted for Thr 45 of exon 1 of TRAC\*01 and Asp 59 of exon 1 of TRBC1\*01 or TRBC2\*01.
- 15
22. A scTCR as claimed in any one of claims 1 to 18, wherein a disulfide bond links cysteine residues substituted for Ser 15 of exon 1 of TRAC\*01 and Glu 15 of exon 1 of TRBC1\*01 or TRBC2\*01.
- 20
23. A scTCR as claimed in any of the preceding claims, wherein the TCR  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments together correspond to the functional variable domain of a first TCR, and the TCR  $\alpha$  and  $\beta$  chain constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to those of a second TCR, the first and second TCRs being from the same species.
- 25
24. A scTCR as claimed in any of claims 1 to 23, wherein the TCR  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments together correspond to the functional variable domain of a first TCR, and the TCR  $\alpha$  and  $\beta$  chain constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to those of a second TCR, the first and second TCRs being from different species.

25. A scTCR as claimed in claim 24 wherein the TCR  $\alpha$  and  $\beta$  chain variable region sequences present in the  $\alpha$  and  $\beta$  segments together correspond to the functional variable domain of a human TCR, and the TCR  $\alpha$  and  $\beta$  chain constant region extracellular sequences present in the  $\alpha$  and  $\beta$  segments correspond to those of a murine TCR.
26. A multivalent T cell receptor (TCR) complex comprising a plurality of sTCRs as claimed in any preceding claim.
27. A scTCR as claimed in any of claims 1 to 25 or a complex as claimed in claim 26 which is covalently linked to a therapeutic agent.
28. A scTCR as claimed in any of claims 1 to 25 or 27, or a plurality thereof, when attached to a particle or bead.
29. A composition comprising a scTCR as claimed in any of the preceding claims and a pharmaceutically acceptable carrier.
30. A method for detecting MHC-peptide complexes, which comprises: providing a scTCR as claimed in any one of claims 1 to 25, or a plurality thereof; contacting the scTCR with the MHC-peptide complexes; and detecting binding of the scTCR to the MHC-peptide complexes.
31. A method of identifying an inhibitor of the interaction between an scTCR as claimed in any one of claims 1 to 25, or a plurality thereof, and a MHC-peptide complex comprising contacting the scTCR with a MHC-peptide binding partner, in the presence of and in the absence of a test compound, and determining whether the presence of the test compound reduces binding of the scTCR to the MHC-peptide complex, such reduction being taken as identifying an inhibitor.

32. A method of identifying a potential inhibitor of the interaction between an scTCR as claimed in any one of claims 1 to 25, or a plurality thereof, and a MHC-peptide complex comprising contacting the scTCR or MHC-peptide binding partner with a test compound and determining whether the test compound binds to the scTCR and/or the MHC-peptide complex, such binding being taken as identifying a potential inhibitor.

33. A nucleic acid molecule comprising a sequence encoding a scTCR as claimed in any one of claims 1 to 25, or a sequence complementary thereto.

34. A vector comprising a nucleic acid molecule as claimed in claim 33.

Figure 1a

atgcagaaggaagtggagcagaactctggacccctcagtgttccagagggagccatt  
gcctctctcaactgcacttacagtgaccgaggttcccagtccttcttctggtacaga  
caatattctgggaaaagccctgagttgataatgtccatatactccaatggtgacaaa  
gaagatggaaggtttacagcacagctcaataaagccagccagtatgtttctctgctc  
atcagagactcccagcccagtgattcagccacctacctctgtgccgttacaactgac  
agctgggggaaattgcagtttggagcagggacccaggttgtggtcaccacagatatac  
cagaaccctgaccctgccgtgtaccagctgagagactctaaatccagtgacaagtct  
gtctgcctattcaccgattttgattctcaaacaatgtgtcacaaagtaaggattct  
gatgtgtatatcacagacaaaagtgtgtgctagacatgaggtctatggacttcaagagc  
aacagtgctgtggcctggagcaacaatctgactttgcatgtgcaaacgccttcaac  
aacagcattattccagaagacaccttcttccccagcccagaaagttcctaa

Figure 1b

atgaacgctggtgtcactcagacccccaaaattccaggtcctgaagacaggacagagc  
atgacactgcagtggtgccaggatatgaaccatgaatacatgtcctggtatcgacaa  
gaccaggcatggggctgaggctgattcattactcagttggtgctggtatcactgac  
caaggagaagtccccaatggctacaatgtctccagatcaaccacagaggatttcccg  
ctcaggctgctgtcggctgctccctcccagacatctgtgtacttctgtgccagcagg  
ccgggactagcgggagggcgaccagagcagttctcgggcccgggcaccagggtcacg  
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gaagcagagatctcccacacccaaaaggccacactggtgtgcctggccacaggcttc  
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gctctgagcagccgcctgagggctctcggccaccttctggcaggacccccgcaaccac  
ttccgctgtcaagtcagttctacgggctctcggagaatgacgagtggaccaggat  
agggccaaaccgctcaccagatcgtcagcgccgaggcctggggtagagcagactaa

Figure 2a

MQ  
K<sub>1</sub>EVEQNSGPL SVPEGAIASL NCTYSDRGSQ SFFWYRQYSG KSPELIMSIY  
SNGDKEDGRF TAQLNKASQY VSLLRDSQP SDSATYLCAY TTDSWGKLQF  
GAGTQVVVTP DIQNPDPVY QLRDSKSSDK SVCLFTDFDS QTNVSQSKDS  
DVYITDKCVL DMRSMDFKSN SAVAWSNKSD FACANAFNNS IIPEDTFFPS  
PESS\*

Figure 2b

M  
N<sub>1</sub>AGVTQTPKF QVLKTGQSMT LQCAQDMNHE YMSWYRQDPG MGLRLIHYSV  
GAGITDQGEV PNGYNVSRST TEDFPLRLLS AAPSQTSVYF CASRPGLAGG  
RPEQYFGPGT RLTVTEDLKN VFPPEVAVFE PSEAEISHTQ KATLVCLATG  
FYPDHVELSW WVNGKEVHSG VCTDPQPLKE QPALNDSRYA LSSRLRVSAT  
FWQDPRNHFR CQVQFYGLSE NDEWTQDRAK PVTQIVSAEA WGRAD\*

P	G	G	G	S	G	G	G	G	S	G	G	G	G
CCC	GGG	GGT	GGC	TCT	GGC	GGT	GGC	GGT	TCA	GGC	GGT	GGC	GGA
GGG	CCC	CCA	CCG	AGA	CCG	CCA	CCG	CCA	AGT	CCG	CCA	CCG	<u>CCT</u>

S	G	G	G	G	S	G	G	G	G	S	G	G	G
TCC	GGC	GGT	GGC	GGT	TCG	GGT	GGC	GGT	GGC	TCA	GGC	GGT	GGC
<u>AGG</u>	CCG	CCA	CCG	CCA	AGC	CCA	CCG	CCA	CCG	AGT	CCG	CCA	CCG

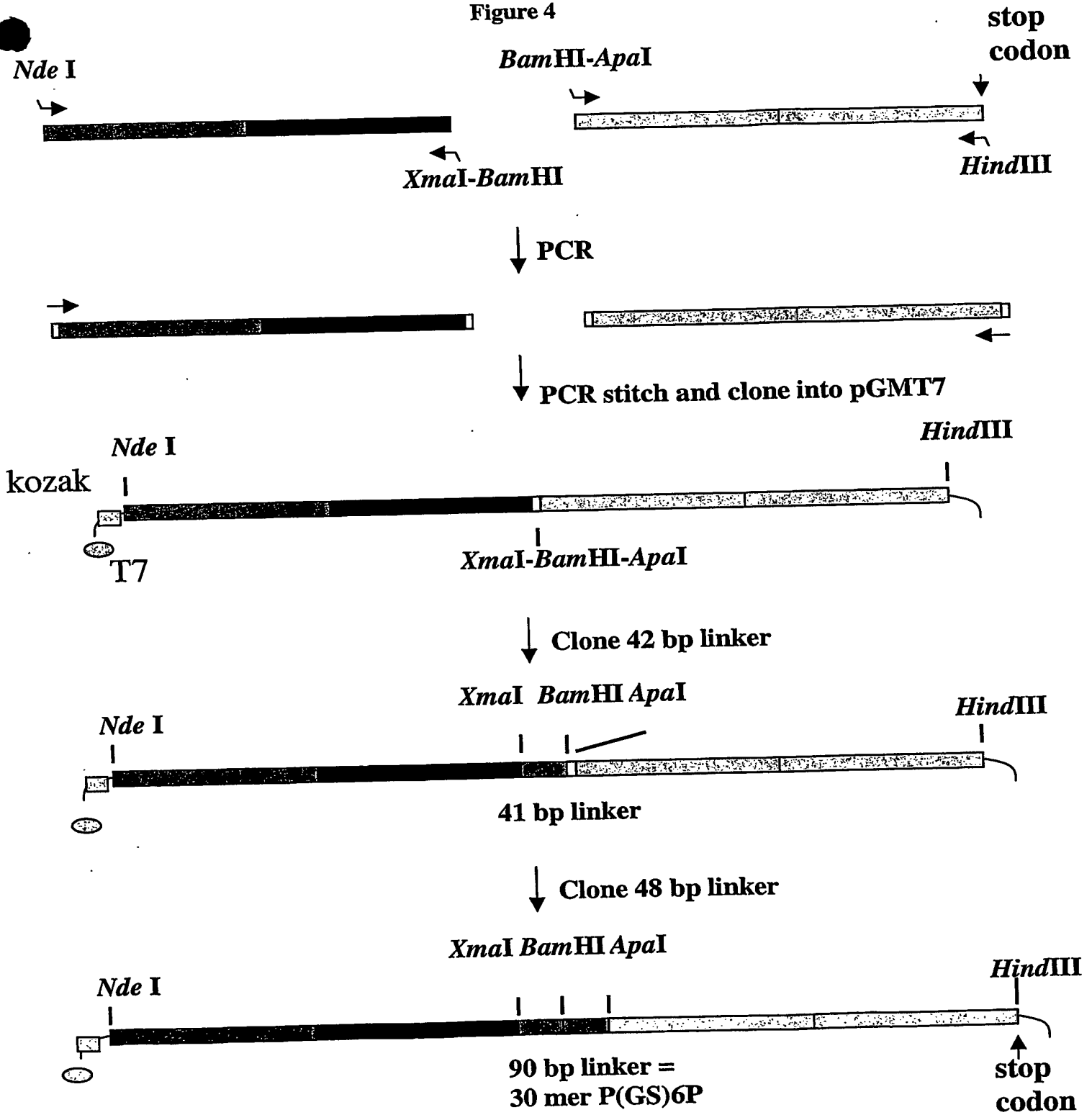
G	P
GGG	CCC
CCC	GGG

Figure 3



4/8

Figure 4



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6/8

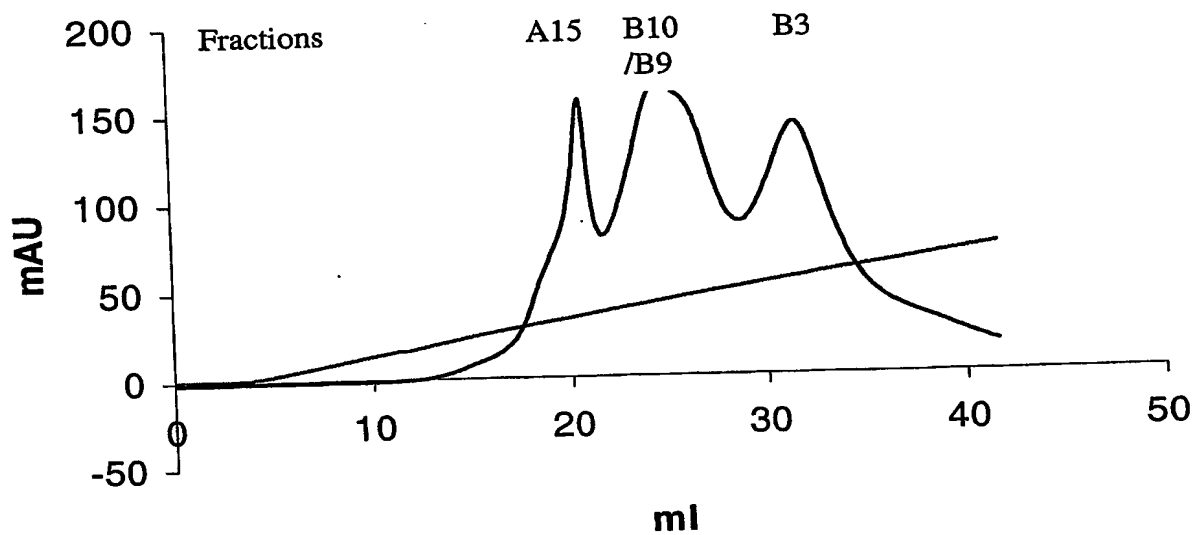


Figure 6

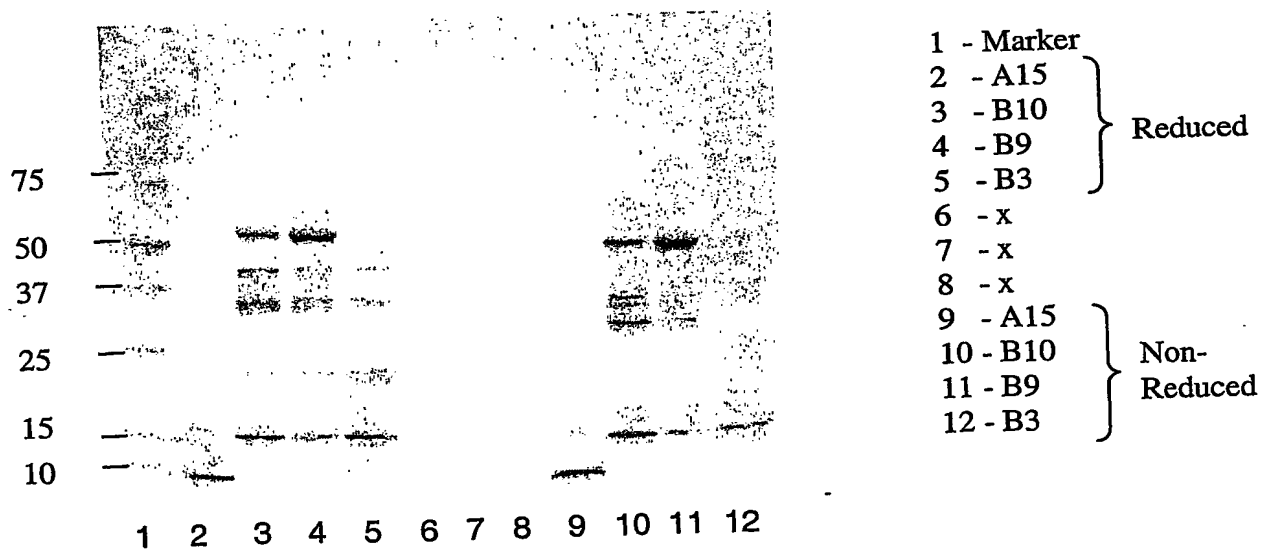


Figure 7

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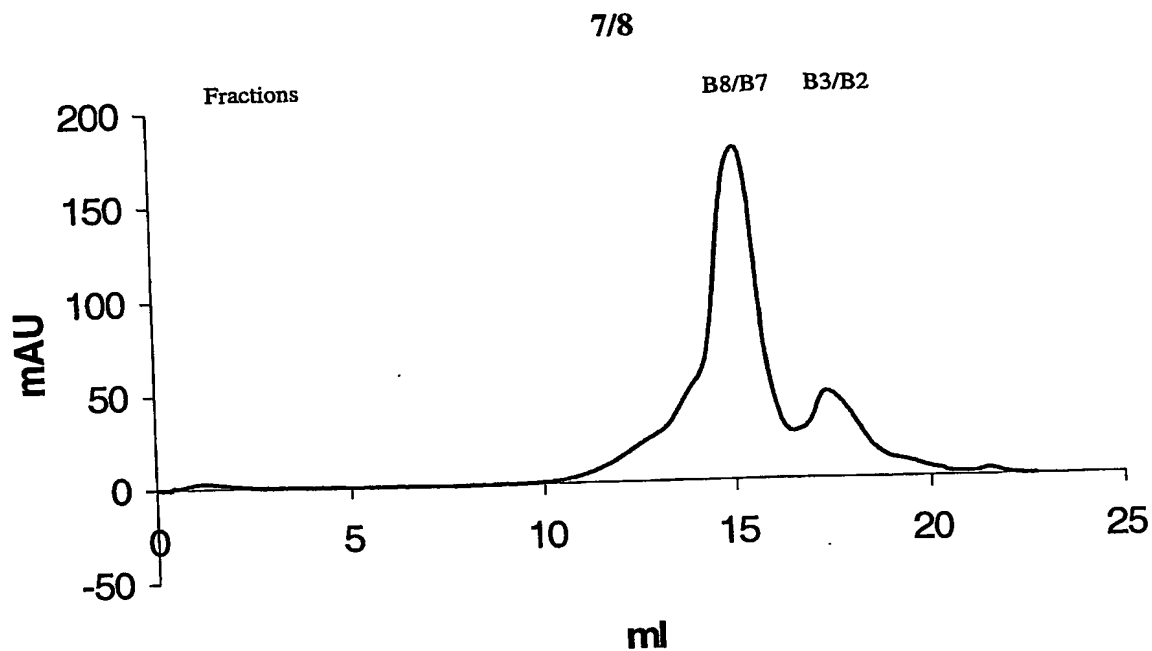


Figure 8

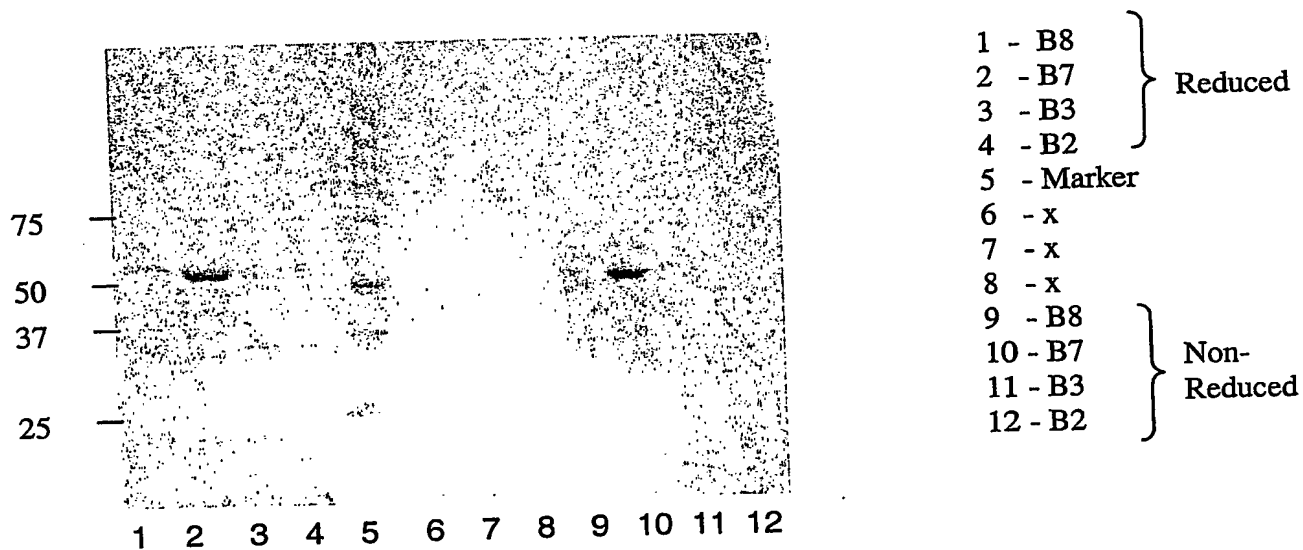


Figure 9

8/8

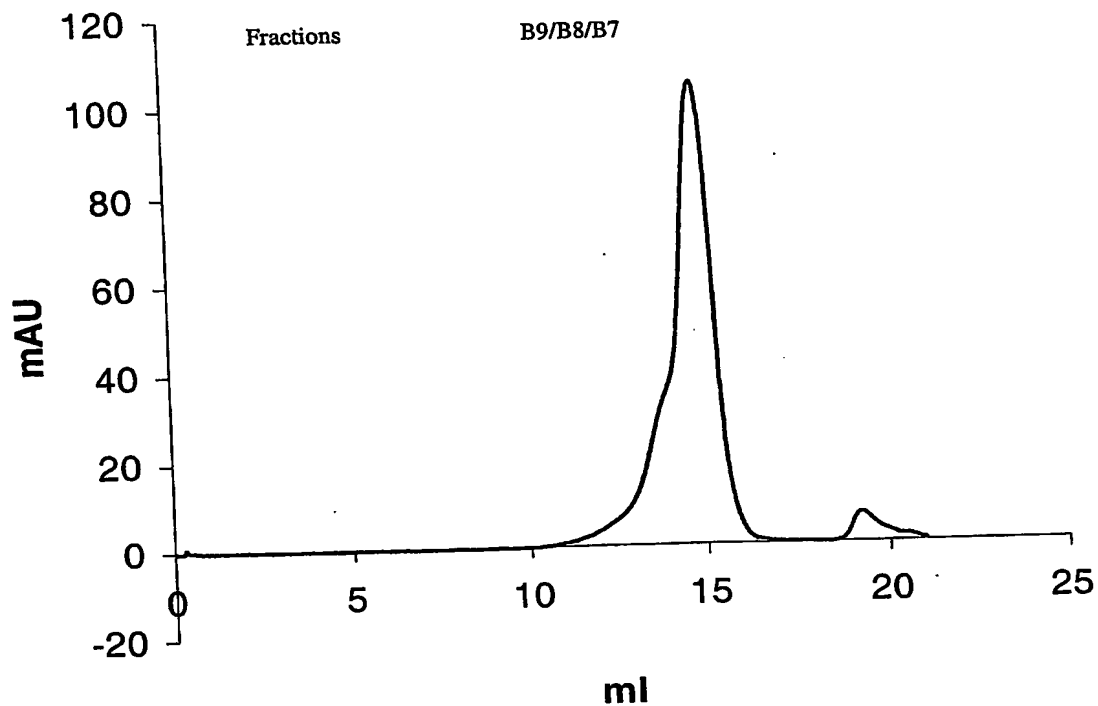


Figure 10

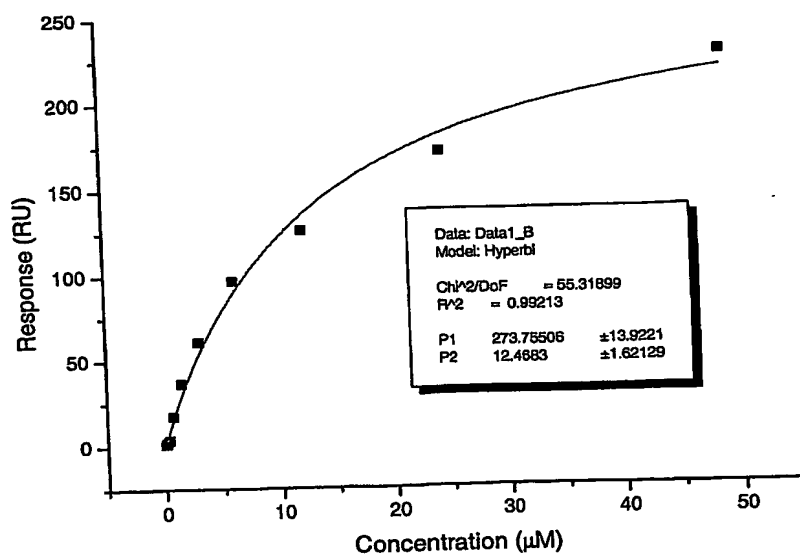


Figure 11